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Effect of Crops and Fertilizer and Soil Nitrogen, Carbon, and Water Content, and on Succeeding Wheat Yields and Quality

ARS-NC-38
March 1976

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CONTENTS

Summary	1
Introduction	1
Procedure	2
Fine sandy loam study	2
Silt loam study	3
Results	3
Soil nitrogen	3
Soil organic carbon	5
Nitrogen balance	5
First 7 years	5
The 9th year	8
The 13th year	8
Crop yields	9
First 7 years	9
Last 6 years	9
Percentage nitrogen in wheat grain	15
Percentage phosphorus in wheat grain	16
Soil water	17
At seeding	17
At harvest	17
Conclusions	19
Acknowledgment	21
Literature cited	21

Effect of Crops and Fertilizer on Soil Nitrogen, Carbon, and Water Content, and on Succeeding Wheat Yields and Quality

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SUMMARY

The effects of crops—wheat, grass, and legumes—with and without nitrogen (N) and phosphorus (P) fertilization, upon soil N and carbon (C) content, soil water, and succeeding crop yields and quality were evaluated on a fine sandy loam and a silt loam. Results were generally similar for the two soil textures. Seven years of fertilized continuous wheat maintained soil N as well as fertilized crested wheatgrass or mixtures of crested wheatgrass and alfalfa or sweetclover. Significant differences in soil N because of cropping and fertilizer treatments occurred where crops were mowed and left on the surface.

Growing alfalfa for 7 years in the same plot apparently resulted in net fixation of over 800 pounds of N per acre. Cropping and fertilizer treatments influenced soil C and soil N similarly, but gains in organic C were higher in

some instances than for N. Generally, organic C content increased as rate of N fertilization increased. Highest mean grain yields for wheat the next 6 years following 7 years of cropping and fertilizer treatments occurred on plots annually cropped to wheat and fertilized with N and P throughout the entire 13-year study.

Plots that had been in sod crops, particularly alfalfa, the first 7 years contained less stored subsoil water in the last 6 years and consequently produced less grain than those which had been in wheat. Nitrogen content of wheat grain was highest following 7 years of crested wheatgrass-alfalfa. Nitrogen fertilizer increased N content of wheat grain but reduced P content, whereas P fertilizer increased P content but reduced N content of grain. Soil productivity was maintained with adequately fertilized annual spring wheat as well as with any other treatment.

INTRODUCTION

Grasses and legumes have long been considered beneficial for improving the physical and chemical properties of soil in humid regions, but their value for soil improvement under dryland conditions in the Great Plains has been questionable. Brown (3)² presented a comprehensive review of the literature on this subject, and concluded that under low rainfall conditions there is generally little, if any, benefit to crops

following sod. Mathews and Cole (6) reported that under dryland conditions, including sod crops in short rotations was not successful. The long-time effect may be beneficial, but the crop immediately following sod may suffer from shortage of water.

Jacks (5) found that the most striking effects of grass on soil were physical. Haas, Evans, and Miles (4) studied the effect of 30 or more years of cropping on N and C content of soil at three locations in the Great Plains. Three years of alfalfa or grass in a 6-year rotation reduced the loss of soil N and C compared to small grain cropping, but neither alfalfa nor grass maintained these elements at their original level.

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²Italic numerals in parentheses refer to Literature Cited, p. 21.

Early studies conducted under dryland conditions did not include the application of commercial fertilizers. Therefore, the studies reported here were initiated to determine the effect of 7 years of grass, legumes, and wheat, with and without fertilizer, on changes in total N and organic C content of the soil, on yields and quality of the crop which followed, and on soil water contents.

One of the studies included a nonharvested treatment in which no plant material was removed during 7 years of cropping to grass, leg-

umes, or wheat. Maximum soil improvement by grasses and legumes would be expected from this treatment. Another objective of the studies was to determine if application of fertilizers to grass and legumes in a rotation would eliminate the necessity of fertilizing grain crops that followed; or would better results be obtained by omitting the sod crops and growing grain crops continuously with fertilizers. Answers to these questions are of uppermost concern if we are to maintain soil productivity under systems of unrestricted production and limited fertilizer availability.

PROCEDURE

Experiments were conducted on two soil types near Mandan, N. Dak.—Parshall fine sandy loam (Pachic Haploboroll) and Eakin silt loam (Typic Haploboroll). The former had been annually cropped about 35 years and the latter 60 years before the experiments were initiated. Average soil N percentages for the two soils at beginning of the experiments were as follows:

Soil depth	Parshall fine sandy loam		Eakin silt loam
	Experiment I	Experiment II	
<i>Inches</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
0 to 6	0.119	0.096	0.198
6 to 12	.120	.094	.132
12 to 24	.088	.072	.088

In these experiments, crested wheatgrass [*Agropyron desertorum* (Fisch.) Schult.], alfalfa [*Medicago sativa* (L.) var. Grimm], sweet clover [*Melilotus officinals* (L.) Lam.], and spring wheat [*Triticum aestivum*, sp. vulgare (Vill., Host) Mackey, var. Pilot] were grown under different fertilizing systems for 7 years. Residual effects of these crops were evaluated by uniformly cropping all areas to spring wheat an additional 6 years. Precipitation for the study period is indicated below:

Period with various cropping and fertilizer treatments		Residual period of uniform cropping to wheat	
Year	Precipitation	Year	Precipitation
	<i>Inches</i>		<i>Inches</i>
1	16.29	8	16.64
2	19.30	9	15.38
3	20.31	10	12.64
4	10.25	11	11.97
5	21.76	12	14.98
6	20.17	13	12.12
7	18.33		

Mean precipitation (46 years)—15.71 inches.

Fine sandy loam study

Two experiments on Parshall fine sandy loam had randomized split plot design with three replications of each treatment. Spring wheat and crested wheatgrass were grown in Experiment I and spring wheat and a mixture of crested wheatgrass and alfalfa or sweet clover were grown in Experiment II. Cropping and fertilizer treatments the first 7 years were as follows:

Experiment I		Experiment II	
Continuous wheat ...	0-0 ¹	Continuous wheat ..	0-0
Do	30-13	Do	30-0
Crested wheatgrass .	0-0	Do	30-13
Do	30-0	Crested wheatgrass—	
Do	30-13	alfalfa	0-0
Do	60-0	Do	0-13
Do	60-13	Crested wheatgrass—	
		sweet clover	0-0
		Do	0-13

¹Figures indicate pounds of N and P, respectively, applied per acre annually, except 42 pounds of P per acre was applied the 1st year.

Each of the main plots, consisting of crop and fertilizer treatments, was divided into two subplots. Crops on half the subplots were harvested and will be referred to as the “harvested” treatment; for example, wheat was combined (grain removed and straw left on the surface), and grass and legumes were mowed and hay removed. All crops, including wheat, on the remaining half of the subplots were mowed and left on the soil surface and will be referred to as the “nonharvested” treatment. Main plots were 21 by 132 ft.

Plots scheduled for wheat were seeded in spring of the 1st year and each spring thereafter through the 13th year. Grass and grass-

legume plots were seeded in spring of the 1st year and were plowed under in fall of the 7th year. Initial stands of grass were poor, but were thickened by reseeded. Legume stands were good to excellent, but because the sweet clover was a biennial, it persisted through only the first 2 years. Good stands of alfalfa remained throughout the 7 years. The entire study was uniformly cropped to spring wheat from the 8th through the 13th year.

Initial fertilizer applications were drilled in spring of the 1st year. Thereafter fertilizer applications were drilled in fall, except for P on wheat which was applied in spring at time of seeding. Only on those wheat plots that had been fertilized the first 7 years were fertilizer treatments continued the last 6 years. All other treatments received no fertilizer during the 6-year residual period.

Yields were obtained from each harvested subplot during the first 7 years and from all subplots (harvested and nonharvested) during the last 6 years. Hay yields were calculated on a 12 percent moisture basis and wheat grain on an air-dry basis. Samples of all harvested crops were collected and analyzed for total N (1) and P (1, 2).

Soil samples were collected and composited from eight locations in each subplot at 0- to 6-, 6- to 12-, and 12- to 24-inch depth increments in spring of the 1st year before any fertilizer had been applied. Samples were again collected in fall of the 7th year before plowing the sod. However, some nonharvested subplots, particularly those which had been in crested wheatgrass-alfalfa mixture, had a thick organic mat on the soil surface. Because only a portion of the mat would become soil organic matter when plowed under, the organic mat was not included in this sampling. However, most of the organic mat was assumed to be decomposed 2 years after plowing, so all subplots were resampled in fall of the 9th year and again at the termination of the study. All soil samples collected throughout the 13-year study were analyzed for total N (1) and organic C (7).

Soil water content was determined gravimetrically by 1-foot intervals to a depth of 6

feet at seeding and harvest from only those plots in wheat the first 7 years and from all plots during the residual period (8th through 13th years) while the area was being uniformly cropped to wheat.

Silt loam study

This study was located on Eakin silt loam and duplicated a number of treatments in the Fine Sandy Loam Study. Eight treatments were replicated three times, with each plot 21 by 104 ft. Treatments were as follows:

	First 7 yrs.	Final 6 years ¹	
		Nonfertilized	Fertilized
Continuous wheat ..	0-0 ²	0-0	30-0
Do	30-13	30-13 ³	60-13
Crested wheatgrass .	30-0	0-0	30-0
Do	30-13	0-0	30-0
Do	60-0	0-0	30-0
Do	60-13	0-0	30-0
Crested wheatgrass- alfalfa	0-0	0-0	30-0
Do	0-13	0-0	30-0

¹Plots split and an additional 30 pounds of N applied to one-half of each plot; all plots seeded to spring wheat each year.

²Figures indicate pounds of N and P per acre, respectively, applied each year, except 42 pounds of P per acre applied the 1st year.

³This treatment was included under nonfertilized treatment for consistency and for ease of data presentation.

All plots in the Silt Loam Study were harvested, and in the 8th year each plot was split lengthwise to allow for the addition of 30 pounds of N per acre to one-half of each plot during each of the final 6 years (fertilized treatment).

The other half-plot received no fertilizer (nonfertilized treatment) except for those wheat plots which were fertilized during the first 7 years. One-half of each of these plots continued to receive 30 pounds of N and 13 pounds of P during the last 6 years, while the other half received 60 pounds of N and 13 pounds of P. Seeding, fertilizing, harvesting, and sampling procedures were the same as for the Fine Sandy Loam Study, except 10 locations instead of 8 were sampled per plot for soil analysis.

RESULTS

Soil Nitrogen

Nitrogen content of the surface 2 feet of

soil on each sampling date is expressed in tables 1 and 2 as a percentage of the N content on the first date.

TABLE 1.—Relative N and organic C contents of surface 2 feet of soil in the Fine Sandy Loam Study using 1st-year data as base

Experiment	First 7 years cropping and fertilizer treatments ¹	Year:	RELATIVE N CONTENT—PERCENTAGE							
			Harvested				Nonharvested			
			1st	7th	9th	13th	1st	7th	9th	13th
I	Wheat:									
	0-0		100	97	97	95	100	98	97	97
	30-13		100	102	99	98	100	102	97	98
	Crested wheatgrass:									
	0-0		100	101	98	97	100	97	94	93
	30-0		100	99	99	96	100	101	99	97
	30-13		100	100	100	96	100	100	101	98
	60-0		100	100	99	99	100	100	101	98
	60-13		100	101	102	100	100	101	103	100
II	Wheat:									
	0-0		100	98	96	94	100	97	97	93
	30-0		100	100	100	99	100	102	100	101
	30-13		100	101	99	98	100	102	103	102
	Crested wheatgrass and alfalfa:									
	0-0		100	100	105	102	100	102	108	108
	0-13		100	101	101	101	100	103	107	107
	Crested wheatgrass and sweet clover:									
	0-0		100	99	101	101	100	97	100	99
	0-13		100	101	102	99	100	99	102	101
RELATIVE ORGANIC C CONTENT—PERCENTAGE										
I	Wheat:									
	0-0		100	94	99	92	100	98	99	93
	30-13		100	102	101	96	100	99	99	97
	Crested wheatgrass:									
	0-0		100	101	103	96	100	98	98	93
	30-0		100	96	102	95	100	101	98	94
	30-13		100	100	107	95	100	101	106	96
	60-0		100	101	106	96	100	102	105	99
	60-13		100	101	108	96	100	104	106	97
II	Wheat:									
	0-0		100	99	99	94	100	98	101	96
	30-0		100	99	102	101	100	104	106	102
	30-13		100	102	105	99	100	104	109	103
	Crested wheatgrass and alfalfa:									
	0-0		100	98	109	101	100	105	117	109
	0-13		100	103	110	103	100	102	112	105
	Crested wheatgrass and sweet clover:									
	0-0		100	102	107	102	100	99	104	102
	0-13		100	101	107	97	100	102	108	102

¹Fertilizer treatment (lbs N and P) annually during first 7 years, except 42 pounds per acre of P was applied only in the 1st year. No fertilizer was applied the

last 6 years except fertilizer applications were continued on the continuous wheat plots.

Soil N content changed little during the first 7 years. In most instances, those treatments which included N fertilizer or alfalfa remained unchanged or gained slightly in soil N, and gains were usually greater in the Silt Loam Study (table 2) than in the Fine Sandy Loam Study (table 1). The nonharvested treatment had little effect upon N content of the soil. By

the 9th year (table 1), 2 years after plowing the sod, soil of the Fine Sandy Loam Study gained the most N (8 percent) under the nonharvested crested wheatgrass and alfalfa treatment.

For the entire 13 years, nonfertilized continuous wheat plots or plots which had been in nonfertilized crested wheatgrass the first 7

TABLE 2.—Relative N and organic C contents of surface 2 feet of soil in the Silt Loam Study using 1st-year data as base

First 7 years cropping and fertilizer treatments ¹	RELATIVE N CONTENT—PERCENTAGE			
	Year:		13th	
	1st	7th	Nonfer- tilized ²	Fertil- ized ³
Wheat:				
0-0 100		98	94	94
30-13 100		102	96	96
Crested wheatgrass:				
30-0 100		103	98	102
30-13 100		102	98	98
60-0 100		104	97	102
60-13 100		102	96	95
Crested wheatgrass and alfalfa:				
0-0 100		102	102	99
0-13 100		103	98	101

Wheat:	RELATIVE ORGANIC C CONTENT—PERCENTAGE			
	Year:		13th	
	1st	7th	Nonfer- tilized ²	Fertil- ized ³
0-0 100		98	95	96
30-13 100		105	101	98
Crested wheatgrass:				
30-0 100		103	100	107
30-13 100		103	103	101
60-0 100		105	102	106
60-13 100		105	100	98
Crested wheatgrass and alfalfa:				
0-0 100		101	103	101
0-13 100		102	100	104

¹Fertilizer treatment (lbs N and P) annually during first 7 years, except 42 pounds per acre of P was applied only in the 1st year.

²Plots split and no fertilizer was applied to one-half of each plot the last 6 years except 30-13 application was continued on continuous wheat plots.

³Plots split and 30 pounds of N per acre was applied to one-half of each the last 6 years except 30-13 application for continuous wheat was increased to 60-13.

years generally lost the most N. Nitrogen applied during the first 7 years (tables 1 and 2) reduced N loss in most instances, but that applied during the last 6 years (table 2) reduced soil N losses in only a few cases. Greatest total soil N gain occurred where crested wheatgrass and alfalfa had been grown together and not harvested. Where crested wheatgrass and sweet

clover had been grown together, the soil N changes were about the same as with fertilized continuous wheat.

Soil Organic Carbon

Changes in organic C (tables 1 and 2) were similar to those for total N except gains in C content were greater in some instances. Therefore, about the same conclusions presented for the total N data apply to the C data. Greatest gain occurred by the 9th year in plots which had been in nonharvested crested wheatgrass and alfalfa (17 percent increase). In several instances, application of fertilizers increased organic C content. Increases in organic C were generally greater on silt loam than on fine sandy loam under similar treatments.

Nitrogen Balance

Nitrogen gains or losses which were unaccounted for, after taking into consideration fertilizer N applied, N removed by crops, and change in total soil N, are presented in tables 3 through 5.

First 7 years

During the first 7 years (tables 3 and 4), only small insignificant changes in soil N (except in nonharvested treatments) occurred because of cropping and fertilizer treatments, as discussed earlier. There was also no significant difference in soil N change between harvested and nonharvested treatments (table 3). Nitrogen application ranged from 0 to 500 pounds per acre for the period, and N in crops removed ranged from 0 (nonharvested) up to 620 pounds per acre from the crested wheatgrass-alfalfa mixture (harvested) with P treatment.

In the Fine Sandy Loam Study (table 3), greatest unaccounted for losses occurred where the higher rates of N (60 pounds per acre) had been applied, particularly where the crop had not been harvested. These significant losses could be due to volatilization, leaching of N below the 2-foot depth of sampling, and in the nonharvested treatments, some of the N was in the organic mat on the soil surface which was not included in the soil sample (8).

Mean unaccounted for losses of N were significantly greater from nonharvested than from

TABLE 3.—Nitrogen balance sheet in pounds per acre for the Fine Sandy Loam Study

Experi- ments	First 7 years cropping and fertilizer treatments	FIRST 7 YEARS							
		Harvested				Nonharvested (7 years)			
		Soil N loss or gain	Fertilizer N added ¹	N removed by crops	Un- accounted for N loss or gain	Soil N loss or gain	Fertilizer N added ¹	N removed by crops	Un- accounted for N loss or gain
I Wheat:									
0-0		-320	0	80	-240	-110	0	0	-110
30-13		+120	240	110	-10	+150	240	0	-90
Crested wheatgrass:									
0-0		+40	0	40	+80	-290	0	0	-290
30-0		-60	250	130	-180	+100	250	0	-150
30-13		-30	250	140	-140	-20	250	0	-270
60-0		-30	500	190	-340	0	500	0	-500
60-13		+40	500	230	-230	+100	500	0	-400
Mean		-30	250	130	-150	-10	250	0	-260
LSD ² (.05) cropping and fertilizer treatments .		NS ³	—	30	250	250	—	—	250
Significance between harvest treatments ..		NS	—	—	* ₃	NS	—	—	*
II Wheat:									
0-0		-150	0	70	-80	-230	0	0	-230
30-0		-30	240	100	-170	+100	240	0	-140
30-13		+60	240	100	-80	+100	240	0	-140
Crested wheatgrass and alfalfa:									
0-0		+30	0	590	+620	+130	0	0	+130
0-13		+50	0	620	+670	+160	0	0	+160
Crested wheatgrass and sweet clover:									
0-0		-50	0	160	+110	-200	0	0	-200
0-13		+40	0	120	+160	-30	0	0	-30
Mean		-10	70	250	+170	0	70	0	-70
LSD (.05) cropping and fertilizer treatments .		NS	—	140	310	200	—	—	200
Significance between harvest treatments ..		NS	—	—	** ₃	NS	—	—	**
7TH THROUGH 9TH YEARS									
I Wheat:									
0-0		+60	0	50	+110	-90	0	50	-40
30-13		-200	60	70	-190	-320	60	70	-310
Crested wheatgrass									
0-0		-160	0	50	-110	-240	0	50	-190
30-0		+10	0	50	+60	-180	0	60	-120
30-13		0	0	50	+50	+60	0	50	+110
60-0		-30	0	50	+20	+120	0	60	+180
60-13		+110	0	60	+170	+110	0	70	+180
Mean		-30	10	50	+10	-80	10	60	-30
LSD (.05) cropping and fertilizer treatments .		NS ³	—	NS	NS	280	—	10	280
Significance between harvest treatments ..		NS	—	*	NS	NS	—	*	NS
II Wheat:									
0-0		-130	0	40	-90	0	0	40	+40
30-0		0	60	60	0	-90	60	50	-100
30-13		-120	60	60	-120	+100	60	70	+110

TABLE 3.—Nitrogen balance sheet in pounds per acre for the Fine Sandy Loam Study—Continued

		7TH THROUGH 9TH YEARS							
		Harvested				Nonharvested (7 years)			
Experi- ments	First 7 years cropping and fertilizer treatments	Soil N loss or gain	Fertilizer N added ¹	N removed by crops	Un- accounted for N loss or gain	Soil N loss or gain	Fertilizer N added	N removed by crops	Un- accounted for N loss or gain
II Wheat—Continued:									
Crested wheatgrass and alfalfa:									
	0-0	+250	0	50	+300	+340	0	60	+400
	0-13	+ 50	0	60	+110	+250	0	60	+310
Crested wheatgrass and sweet clover:									
	0-0	+110	0	50	+160	+190	0	50	+240
	0-13	+ 70	0	50	+120	+140	0	60	+200
	Mean	+ 30	20	50	+ 60	+130	20	60	+170
LSD (.05) cropping and fertilizer treatments .		NS	—	10	NS	260	—	10	260
Significance between harvest treatments ..		NS	—	**	NS	NS	—	**	NS
ENTIRE 13 YEARS									
I Wheat:									
	0-0	—480	0	220	—260	—220	0	110	—110
	30-13	—120	420	280	—260	—120	420	160	—380
Crested wheatgrass:									
	0-0	—240	0	160	— 80	—620	0	140	—480
	30-0	—260	250	250	—260	—250	250	130	—370
	30-13	—280	250	270	—260	—180	250	130	—300
	60-0	—100	500	320	—280	—170	500	140	—530
	60-13	+ 30	500	360	—110	— 30	500	150	—380
	Mean	—210	270	270	—210	—230	270	140	—360
LSD (.05) cropping and fertilizer treatments .		270	—	40	NS	290	—	—	NS
Significance between harvest treatments ..		NS	—	—	*	NS	—	—	*
II Wheat:									
	0-0	—410	0	170	—240	—500	0	110	—390
	30-0	— 40	420	240	—220	+ 50	420	120	—250
	30-13	—120	420	230	—310	+100	420	150	—170
Crested wheatgrass: and alfalfa:									
	0-0	+130	0	710	+840	+430	0	150	+580
	0-13	+ 50	0	760	+810	+380	0	150	+530
Crested wheatgrass and sweet clover:									
	0-0	+ 60	0	270	+330	— 80	0	120	+ 40
	0-13	— 70	0	230	+160	+ 30	0	120	+150
	Mean	— 60	120	370	+190	+ 60	120	130	+ 70
LSD (.05) cropping and fertilizer treatments .		NS	—	150	420	290	—	—	290
Significance between harvest treatments ..		NS	—	—	NS	NS	—	—	NS

¹Values do not always correspond to product of fertilizer rate times years because application rates in field were not always equal to calibrated rates.

²Least significant difference.

³In this and following tables, *, ** significant at the 5 percent and 1 percent levels of probability, respectively; NS—not significant.

TABLE 4.—Nitrogen balance sheet in pounds per acre for Silt Loam Study for first 7 years

First 7 years cropping and fertilizer treatments	Soil N loss or gain	Fertil- izer N added ¹	N re- moved by crops	Unac- counted for N loss or gain
Wheat:				
0-0	—180	0	80	—100
30-13	+180	230	140	+ 90
Crested wheatgrass:				
30-0	+210	230	120	+100
30-13	+150	230	130	+ 50
60-0	+290	460	190	+ 20
60-13	+190	460	210	— 60
Crested wheatgrass and alfalfa:				
0-0	+150	0	380	+530
0-13	+210	0	460	+670
Mean	+150	200	210	+160
LSD ² (.05) cropping and fertilizer treatments	NS ³	—	40	370

¹See footnote 1, table 3.

²See footnote 2, table 3.

³See footnote 3, table 3.

harvested plots. A portion of the difference was apparently due to the unmeasured N in the organic mat on the nonharvested plots. Greatest unaccounted for gains (670 pounds per acre) occurred with the crested wheatgrass-alfalfa 0-13 treatment in both soils. Thus, if this gain reflects net N fixation, these results indicate alfalfa fixed nearly 100 pounds of N per acre per year for the seven cropping seasons. More N was possibly fixed by the alfalfa, but it may have been lost by volatilization or perhaps by N leaching below the 2-foot sampling depth. Therefore, the 100-pound N fixation figure is considered a conservation estimate.

The 9th year

Soil N increased in a number of the treatments in the Fine Sandy Loam Study from the 7th through the 9th year following plowing under the sod and organic mat (table 3). Greatest gains occurred in the crested wheatgrass-alfalfa nonharvested treatments. Unaccounted for N gain for this treatment was 400 pounds per acre indicating that considerable N was in the organic mat, roots, and crowns of the grass and alfalfa. However, there was a 300 pound per acre unaccounted for gain of N in the harvested treatment, indicating that most of the N was stored in roots and crowns during 7

years growth. If this 300 pounds is added to the 620 pounds unaccounted for during the first 7 years (table 3), then total fixation of N by alfalfa was over 900 pounds during the 7 years.

The 13th year

During the entire 13 years, greatest loss of soil N occurred where continuous wheat or crested wheatgrass alone had been grown without N fertilizer (tables 3 and 5). In most cases, application of N fertilizer reduced loss of soil N. There was no significant difference between mean soil N loss or gain of harvested and nonharvested treatments. Greatest gain in soil N again occurred in the Fine Sandy Loam Study under the nonharvested crested wheatgrass-alfalfa treatment.

Unaccounted for losses of N occurred in both soils under all continuous wheat and crested wheatgrass treatments. Greatest unaccounted for N loss in the Fine Sandy Loam Study was from the crested wheatgrass 60-0 nonharvested treatment.

In the Silt Loam Study, the greatest unaccounted for loss was 740 pounds per acre from the crested wheatgrass 60-13 treatment that received additional N fertilizer during the last 6 years. As mentioned earlier, the unaccounted for loss may have been due to volatilization or to leaching of nitrate below the 2-foot depth of sampling.

Harvesting treatment during the first 7 years had a significant effect on mean unaccounted for nitrogen loss by the 13th year in Experiment I, but not on mean gain in Experiment II.

Greatest gain in unaccounted for nitrogen (840 pounds per acre) was in the Fine Sandy Loam Study from the crested wheatgrass-alfalfa 0-0 harvested treatments (table 3). The 840-pound gain is assumed to be a conservative estimate of the net amount of N fixed by alfalfa because some of the fixed N may have been lost by volatilization or by leaching below the 2-foot depth.

In the Silt Loam Study (table 5), unaccounted for N loss or gain was not significantly influenced by the 30-pound application of N per acre each year during the last 6 years. However, crop N removal was consistently higher from the fertilized plots.

TABLE 5.—Nitrogen balance sheet in pounds per acre for Silt Loam Study for entire 13 years

First 7 years cropping and fertilizer treatments	NONFERTILIZED (LAST 6 YEARS) ¹				FERTILIZED (LAST 6 YEARS) ²			
	Soil N loss or gain	Fertilizer N added ³	N removed by crops	Unaccounted for N loss or gain	Soil N loss or gain	Fertilizer N added	N removed by crops	Unaccounted for N loss or gain
Wheat:								
0-0	—490	0	170	—320	—480	180	180	—480
30-13	—260	410	260	—410	—300	590	280	—610
Crested wheatgrass:								
30-0	—140	230	220	—150	+110	410	230	— 70
30-13	—180	230	220	—190	—140	410	250	—300
60-0	—270	460	290	—440	+150	640	300	—190
60-13	—290	460	310	—440	—420	640	320	—740
Crested wheatgrass and alfalfa:								
0-0	+140	0	480	+620	— 90	180	490	+220
0-13	—160	0	560	+400	+ 70	180	580	+470
Mean	—210	220	310	—120	—140	400	330	—210
LSD ⁴ (.05) cropping and fertilizer treatments	NS ⁵	—	50	620	NS	—	50	500
Significance of fertili- zation last 6 years	NS	—	***	NS	NS	—	**	NS

¹No fertilizer applied to one-half of each plot last 6 years except 30-13 rate was continued on continuous wheat.

²One-half of each plot received 30 pounds of N last 6 years except the 30-13 treatment for continuous wheat was increased to 60-13.

³See footnote 1, table 3.

⁴See footnote 2, table 3.

⁵See footnote 3, table 3.

Crop Yields

First 7 years

Crop yields from both studies during the first 7 years are presented in table 6. Hail reduced wheat yields various amounts in 4 of the 7 years in the Fine Sandy Loam Study, including the 3d year when hail was so severe that no yields were recorded. Fertilizer greatly increased crested wheatgrass yields, but a mixture of crested wheatgrass and alfalfa produced more than fertilized crested wheatgrass alone. Mean yields of a crested wheatgrass and sweet clover mixture were more than from nonfertilized crested wheatgrass, but less than from fertilized crested wheatgrass. Yields of comparable treatments of crested wheatgrass alone or in combination with alfalfa averaged higher in the Fine Sandy Loam Study than in the Silt Loam Study.

Last 6 years

The effect of 7 years of cropping and fertilizer treatments on subsequent continuous wheat yields is shown in tables 7 and 8. In the Fine Sandy Loam Study, fertilizer was applied during the last 6 years to only those wheat plots which had received fertilizer the first 7 years (table 7). These plots therefore received their respective fertilizer rates throughout the entire 13 years. In contrast, no fertilizer was applied the last 6 years to any of the plots that had previously been in crested wheatgrass or mixtures of crested wheatgrass and alfalfa or sweet clover. Plots in the Silt Loam Study were split and fertilizer applied as indicated in the procedure and in the footnotes of table 8.

In the Fine Sandy Loam Study Experiment I (table 7), highest wheat yields, except in low rainfall years (11 and 13), occurred with continuous wheat that received 30 pounds of N and 13 pounds of P annually throughout the study. Seven years of crested wheatgrass with even higher rates of N had no significant resi-

TABLE 6.—Yields of wheat, grass, and legumes during the first 7 years from the Fine Sandy Loam and Silt Loam Studies

First 7 years cropping and fertilizer treatments ¹		Year:	Yields per acre (grass and legumes in pounds, wheat in bushels)							
			1st ²	2d	3d	4th	5th	6th	7th	Mean
FINE SANDY LOAM STUDY—EXPERIMENT I										
Wheat:										
0-0			³ 10.4	³ 8.7	—(³)	15.1	14.2	³ 12.6	20.8	13.6
30-13			³ 11.0	³ 13.5	—(³)	15.9	19.7	³ 15.3	25.9	16.9
Crested wheatgrass:										
0-0			—	270	520	270	1,230	440	390	520
30-0			—	690	2,410	1,040	4,430	1,740	1,050	1,890
30-13			—	1,060	2,470	1,310	4,340	1,460	1,000	1,940
60-0			—	570	2,980	1,460	5,440	2,160	1,500	2,350
60-13			—	910	3,200	1,400	6,420	2,460	1,570	2,660
FINE SANDY LOAM STUDY—EXPERIMENT II										
Wheat:										
0-0			³ 10.6	³ 9.5	—(³)	12.1	8.9	³ 7.1	18.2	11.1
30-0			³ 12.4	³ 12.5	—(³)	11.0	17.5	³ 8.3	22.0	14.0
30-13			³ 13.7	³ 13.2	—(³)	10.4	17.3	³ 13.0	21.7	14.9
Crested wheatgrass and alfalfa:										
0-0			—	3,470	2,880	2,530	5,430	4,640	5,060	4,000
0-13			—	2,930	2,960	2,450	6,620	4,670	5,370	4,170
Crested wheatgrass and sweet clover:										
0-0			—	2,040	950	480	1,430	890	3,160	1,490
0-13			—	2,100	1,100	470	1,790	820	1,760	1,340
SILT LOAM STUDY										
Wheat:										
0-0			7.2	11.0	—(³)	16.1	5.9	7.9	20.7	11.5
30-13			11.2	13.9	—(³)	23.9	11.6	17.0	31.2	18.1
Crested wheatgrass:										
30-0			—	840	1,170	680	3,520	1,340	1,730	1,550
30-13			—	1,150	1,390	540	4,050	1,390	1,760	1,710
60-0			—	1,190	1,450	790	4,752	1,760	2,530	2,080
60-13			—	1,480	1,960	960	5,610	2,150	2,940	2,520
Crested wheatgrass and alfalfa:										
0-0			—	2,900	2,710	1,360	4,550	2,190	1,880	2,610
0 13			—	3,260	3,220	2,020	5,730	2,810	2,560	3,270

¹Fertilizer treatment (1b N and P) annually for first 7 years, except 42 pounds per acre of P applied only in the 1st year.

²Grass and legumes seeded but not harvested in 1st year.

³Hail damaged.

dual effect on wheat grain yields. These results are shown graphically in figure 1. Previous harvesting treatment significantly influenced wheat yields that followed only in the 10th year in Experiment I (table 7).

Wheat yields during the 8th to 13th years in Experiment II (table 7) were influenced by previous cropping and fertilizer treatments except in the 11th year for harvested treatments

and in the 13th year for nonharvested treatments. Continuous wheat fertilized with 30 pounds of N and 13 pounds of P per acre annually throughout the study produced highest yields in 3 of the last 6 years. Yields of wheat from the crested wheatgrass-alfalfa treatment fertilized with 13 pounds of P per acre annually were higher than those from continuous wheat without fertilizer in 3 of the last 6 years and

TABLE 7.—Wheat yields and percentages of N and P in grain produced the last 6 years following 7 years of cropping and fertilizer treatments in the Fine Sandy Loam Study

Experiment	First 7 years cropping and fertilizer treatments	Year:	WHEAT YIELD (BUSHELS PER ACRE)													
			8th		9th		10th		11th		12th		13th		Mean	
			H ¹	NH ²	H	NH	H	NH	H	NH	H	NH	H	NH	H	NH
I	Wheat:															
	0-0 ³		19.5	17.6	19.3	17.2	21.8	19.3	12.0	8.9	21.3	17.8	11.1	5.0	17.5	14.3
	30-13		22.3	25.0	25.5	25.4	30.2	30.8	11.2	6.4	33.7	30.0	10.5	5.6	22.2	20.5
	Crested wheatgrass:															
	0-0		16.6	19.2	17.7	20.1	19.2	22.5	9.8	12.0	20.4	23.3	6.1	12.0	15.0	18.2
	30-0		16.7	19.0	15.5	18.1	20.6	21.6	4.9	4.3	21.9	24.8	4.3	4.4	14.0	15.4
	30-13		17.3	18.2	19.6	19.6	21.6	21.7	7.9	7.9	23.3	22.4	7.6	4.3	16.2	15.7
	60-0		16.8	18.1	17.0	17.8	21.9	27.0	6.9	5.6	22.1	24.7	5.0	4.5	15.0	16.3
	60-13		17.1	17.8	18.2	21.0	22.0	26.7	7.2	6.5	22.5	25.4	3.9	5.7	15.2	17.2
	Mean		18.0	19.3	19.0	19.9	22.5	24.2	8.6	7.4	23.6	24.1	6.9	5.9	16.4	16.8
LSD ⁴ (.05) cropping and fertilizer treatments ...			NS ⁵	NS	4.0	3.8	3.6	5.2	NS	NS	3.9	4.5	NS	NS	4.8	NS
Significance between harvest treatments			NS		NS		* ⁵		NS		NS		NS		NS	
II	Wheat:															
	0-0		14.4	16.2	14.7	16.6	17.2	18.9	6.8	7.7	15.8	17.8	4.8	4.6	12.3	13.6
	30-0		16.7	14.7	19.5	16.5	24.1	22.8	5.1	2.5	23.7	20.1	3.6	1.6	15.4	13.0
	30-13		20.3	22.4	21.8	24.3	24.1	27.1	5.0	4.7	26.0	26.9	5.4	5.3	17.1	18.4
	Crested wheatgrass and alfalfa:															
	0-0		12.4	13.3	15.4	19.3	21.8	25.5	3.5	2.1	18.6	23.0	1.7	1.8	12.2	14.2
	0-13		14.7	11.3	18.9	18.3	26.7	26.5	5.9	2.7	22.0	25.5	4.7	2.4	15.5	14.4
	Crested wheatgrass and sweet clover:															
	0-0		16.0	19.7	18.2	17.9	19.4	21.3	5.9	6.8	17.3	19.5	3.0	5.3	13.3	15.1
	0-13		15.8	18.4	16.2	19.5	19.0	20.5	6.2	5.9	18.6	20.2	3.1	3.9	13.2	14.7
	Mean		15.8	16.6	17.8	18.9	21.8	23.2	5.5	4.6	20.3	21.9	3.8	3.6	14.1	14.8
LSD (.05) cropping and fertilizer treatments ...			3.8	2.6	3.8	3.5	3.8	3.7	NS	3.7	3.8	2.4	2.1	NS	2.5	2.5
Significance between harvest treatments			*		*		** ⁵		NS		**		NS		**	
PERCENTAGE N IN WHEAT GRAIN																
I	Wheat:															
	0-0 ³		2.47	2.52	2.33	2.45	2.20	2.25	2.60	2.67	2.26	2.25	2.72	3.07	2.43	2.54
	30-13		2.48	2.58	2.51	2.57	2.14	2.17	2.78	2.99	2.18	2.28	3.11	3.26	2.53	2.64
	Crested wheatgrass:															
	0-0		2.53	2.46	2.43	2.42	2.18	2.14	2.66	2.61	2.25	2.24	3.05	2.77	2.52	2.44
	30-0		2.81	2.82	2.73	2.80	2.27	2.26	2.86	2.91	2.37	2.30	3.15	3.21	2.70	2.72
	30-13		2.62	2.65	2.48	2.50	2.12	2.14	2.77	2.72	2.20	2.28	2.97	3.24	2.53	2.59
	60-0		2.87	2.73	2.76	3.05	2.27	2.39	3.06	2.90	2.38	2.36	3.19	3.30	2.76	2.79
	60-13		3.32	3.49	2.76	2.82	2.22	2.16	2.87	2.83	2.35	2.31	3.16	3.07	2.78	2.78
	Mean		2.73	2.75	2.57	2.66	2.20	2.22	2.80	2.80	2.28	2.29	3.05	3.13	2.61	2.64
LSD (.05) cropping and fertilizer treatments ...			0.20	0.29	0.29	0.26	NS ⁵	0.14	NS	NS	0.13	NS	NS	NS	0.20	0.18
Significance between harvest treatments			NS		**		NS		NS		NS		NS		NS	
II	Wheat:															
	0-0		2.63	2.45	2.51	2.48	2.21	2.16	2.92	2.75	2.38	2.33	3.11	3.17	2.63	2.56
	30-0		2.81	3.00	2.87	3.15	2.42	2.50	3.24	3.44	2.67	2.66	3.37	3.37	2.90	3.02
	30-13		2.52	2.60	2.58	2.62	2.20	2.17	3.04	3.03	2.15	2.26	3.19	3.17	2.61	2.64

TABLE 7.—Wheat yields and percentages of N and P in grain produced the last 6 years following 7 years of cropping and fertilizer treatments in the Fine Sandy Loam Study—Continued

First 7 years cropping and fertilizer treatments			PERCENTAGE N IN WHEAT GRAIN													
			8th		9th		10th		11th		12th		13th		Mean	
Experi- ment	Year:	H	NH	H	NH	H	NH	H	NH	H	NH	H	NH	H	NH	
II Wheat—Continued:																
Crested wheatgrass and alfalfa:																
0-0			3.42	3.48	3.27	3.44	2.67	3.02	3.22	3.34	2.38	2.92	3.36	3.42	3.05	3.27
0-13			3.08	3.25	3.26	3.58	2.46	3.13	2.89	3.02	2.37	2.84	3.18	3.42	2.87	3.21
Crested wheatgrass and sweet clover:																
0-0			2.52	2.60	2.77	2.64	2.29	2.20	3.13	3.04	2.43	2.35	3.30	3.22	2.74	2.68
0-13			2.78	2.70	2.62	2.66	2.22	2.20	2.92	2.92	2.29	2.29	3.31	3.17	2.69	2.66
Mean			2.82	2.87	2.84	2.94	2.35	2.48	3.05	3.08	2.38	2.52	3.26	3.28	2.78	2.86
LSD (.05) cropping and fertilizer treatments ...			0.30	0.23	0.18	0.14	0.12	0.15	NS	0.33	0.19	0.24	NS	0.19	0.13	0.13
Significance between harvest treatments			NS		**		NS		NS		**		NS		**	
PERCENTAGE P IN GRAIN																
I Wheat:																
0-0 ³			0.509	0.529	0.532	0.562	0.481	0.479	0.529	0.543	0.551	0.543	0.492	0.482	0.516	0.523
30-13			.531	.505	.562	.579	.481	.481	.533	.520	.525	.513	.506	.478	.523	.513
Crested wheatgrass:																
0-0			.540	.519	.579	.583	.498	.485	.553	.540	.570	.542	.501	.475	.540	.524
30-0			.533	.501	.582	.561	.459	.451	.523	.507	.537	.522	.477	.492	.518	.506
30-13			.517	.525	.589	.592	.493	.494	.542	.520	.537	.525	.529	.533	.534	.532
60-0			.518	.497	.553	.574	.451	.423	.528	.515	.521	.531	.495	.481	.511	.504
60-13			.555	.548	.595	.615	.493	.475	.529	.533	.557	.523	.519	.515	.541	.535
Mean			.529	.518	.570	.581	.479	.470	.534	.525	.542	.528	.503	.494	.526	.519
LSD (.05) cropping and fertilizer treatments ...			NS ⁵	0.025	NS	NS	NS	0.039	NS	NS	NS	NS	NS	0.026	NS	NS
Significance between harvest treatments			*		NS		NS		NS		NS		NS		NS	
II Wheat:																
0-0			0.502	0.509	0.569	0.547	0.491	0.476	0.508	0.530	0.539	0.523	0.496	0.492	0.518	0.513
30-0			.429	.456	.498	.543	.407	.425	.483	.512	.514	.514	.472	.489	.467	.490
30-13			.496	.517	.569	.575	.487	.503	.531	.535	.515	.513	.481	.465	.513	.518
Crested wheatgrass and alfalfa:																
0-0			.489	.514	.508	.548	.413	.398	.513	.519	.506	.500	.492	.485	.487	.494
0-13			.508	.525	.591	.605	.485	.481	.523	.547	.543	.533	.497	.464	.524	.526
Crested wheatgrass and sweet clover:																
0-0			.522	.510	.535	.533	.483	.475	.555	.535	.528	.518	.479	.487	.517	.510
0-13			.531	.533	.585	.581	.532	.516	.552	.543	.538	.519	.519	.517	.543	.535
— Mean			.497	.509	.551	.562	.471	.468	.524	.532	.526	.517	.491	.486	.510	.512
LSD (.05) cropping and fertilizer treatments ...			0.031	0.027	0.030	0.028	0.026	0.031	0.024	NS	NS	NS	0.026	NS	0.014	0.016
Significance between harvest treatments			*		NS		NS		NS		NS		NS		NS	

¹Crops harvested and removed first 7 years.

²Crops mowed and left on surface first 7 years.

³Fertilizer treatment figures represent pounds of N and P per acre, respectively, annually 42 pounds

per acre of P applied in 1st year only.

⁴See footnote 2, table 3.

⁵See footnote 3, table 3.

TABLE 8.—Wheat yields and percentages of N and P produced for the last 6 years following 7 years of cropping and fertilizer treatments in the Silt Loam Study

First 7 years cropping and fertilizer treatments	Year:	WHEAT YIELD (BUSHEL PER ACRE)													
		8th		9th		10th		11th		12th		13th		Mean	
		NF ¹	F ²	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F
Continuous wheat:															
0-0 ³	14.1	17.0	11.4	12.2	14.5	18.6	5.4	5.7	15.6	15.2	4.4	2.7	10.9	1.19	
30-13	21.9	24.2	15.8	13.1	19.9	23.7	4.5	5.4	24.1	23.1	3.6	3.1	15.0	15.4	
Crested wheatgrass:															
30-0	10.5	13.4	12.1	11.0	16.9	19.6	5.6	5.4	15.5	14.6	4.1	2.7	10.8	11.1	
30-13	12.4	14.3	14.2	12.2	14.9	21.8	4.6	4.8	18.3	20.8	4.7	4.9	11.5	13.1	
60-0	12.7	12.3	11.7	10.2	17.6	19.1	5.9	5.0	15.3	14.4	3.6	2.6	11.1	10.6	
60-13	10.4	11.9	13.8	11.0	16.6	22.1	5.2	4.6	19.2	20.3	3.8	3.4	11.5	12.2	
Crested wheatgrass and alfalfa:															
0-0	6.5	7.2	10.6	9.9	19.6	20.9	6.0	5.5	15.9	15.3	3.2	2.3	10.3	10.2	
0-13	7.2	7.4	10.7	9.1	21.9	24.7	5.1	4.6	19.4	20.0	3.9	3.3	11.4	11.5	
Mean	12.0	13.5	12.5	11.1	17.7	21.3	5.3	5.1	17.9	18.0	3.9	3.1	11.6	12.0	
LSD ⁴ (.05) cropping and fertilizer treatments ...	5.0	6.3	2.2	2.2	2.5	2.9	NS ⁵	NS	1.7	3.0	NS	NS	1.4	2.1	
Significance between last 6 years' fertilizer treatments	* ⁵		** ⁵		**		NS		NS		*		NS		
PERCENTAGE N IN WHEAT GRAIN															
Wheat:															
0-0	2.30	2.41	2.43	2.84	2.28	2.30	3.02	3.21	2.44	2.91	2.97	3.07	2.57	2.79	
30-13	2.26	2.54	2.62	3.01	2.20	2.45	3.48	3.36	2.50	2.92	3.35	3.37	2.74	2.94	
Crested wheatgrass:															
30-0	3.01	2.85	2.99	3.28	2.25	2.51	3.13	3.29	2.64	3.21	3.19	3.33	2.87	3.08	
30-13	2.60	2.91	2.62	3.18	2.15	2.26	3.29	3.23	2.27	2.63	3.01	3.19	2.66	2.90	
60-0	2.91	3.16	3.05	3.42	2.33	2.85	3.43	3.38	2.65	3.31	3.29	3.57	2.94	3.28	
60-13	2.74	3.16	2.76	3.29	2.20	2.26	3.32	3.36	2.31	2.76	3.34	3.29	2.78	3.02	
Crested wheatgrass and alfalfa:															
0-0	3.51	3.63	3.47	3.56	2.73	3.09	3.45	3.26	2.66	3.19	3.30	3.34	3.19	3.34	
0-13	3.31	3.52	3.37	3.64	2.33	2.94	3.36	3.52	2.39	2.75	3.22	3.57	3.00	3.32	
Mean	2.83	3.02	2.91	3.28	2.31	2.58	3.31	3.33	2.48	2.96	3.21	3.34	2.84	3.08	
LSD (.05) cropping and fertilizer treatments ...	0.23	0.46	0.26	0.29	0.11	0.26	0.26	NS ⁵	0.17	0.25	0.19	0.23	0.15	0.19	
Significance between last 6 years' fertilizer treatments	**		**		**		NS		**		**		**		
PERCENTAGE P IN WHEAT GRAIN															
Wheat:															
0-0	0.470	0.393	0.530	0.483	0.472	0.432	0.493	0.459	0.501	0.454	0.495	0.485	0.494	0.451	
30-13	.468	.453	.601	.579	.511	.503	.493	.464	.532	.536	.526	.532	.522	.511	
Crested wheatgrass:															
30-0	.486	.433	.521	.471	.457	.425	.499	.489	.495	.458	.497	.492	.492	.461	
30-13	.525	.486	.565	.587	.529	.511	.517	.527	.517	.525	.529	.536	.530	.529	
60-0	.475	.396	.485	.473	.431	.426	.449	.453	.471	.467	.484	.495	.466	.452	
60-13	.521	.545	.556	.588	.528	.511	.493	.455	.507	.525	.524	.508	.522	.522	
Crested wheatgrass and alfalfa:															
0-0	.492	.493	.510	.492	.407	.379	.455	.481	.476	.443	.505	.513	.474	.467	
0-13	.557	.555	.609	.608	.496	.490	.501	.536	.520	.510	.537	.545	.437	.541	
Mean	.499	.469	.547	.535	.479	.460	.488	.483	.502	.490	.512	.516	.505	.492	
LSD (.05) cropping and fertilizer treatments ...	0.053	0.060	0.048	0.044	0.041	0.065	NS ⁵	NS	0.024	0.025	0.027	NS	0.029	0.030	
Significance between last 6 years' fertilizer treatments	**		NS		*		NS		*		NS		*		

See footnotes at bottom page 14.

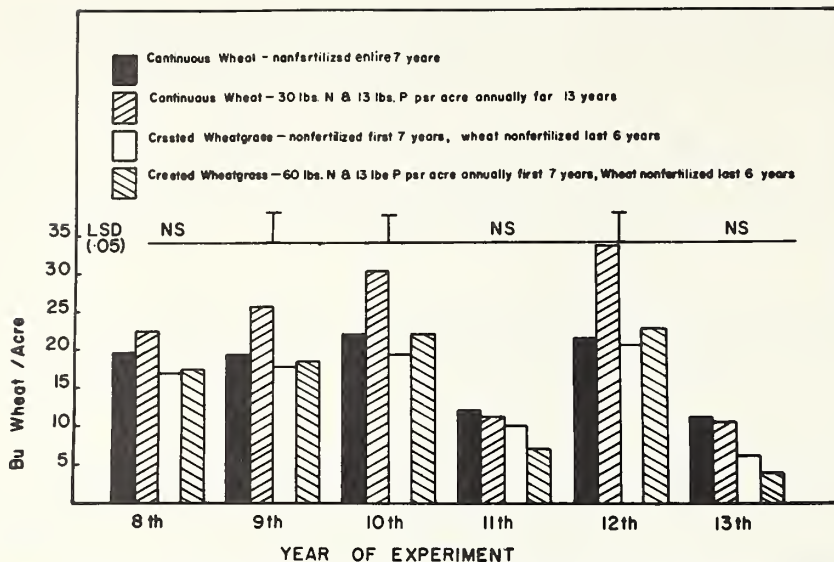


FIGURE 1.—Wheat yields following different cropping and fertilizer treatments (harvested) in Experiment I of the Fine Sandy Loam Study.

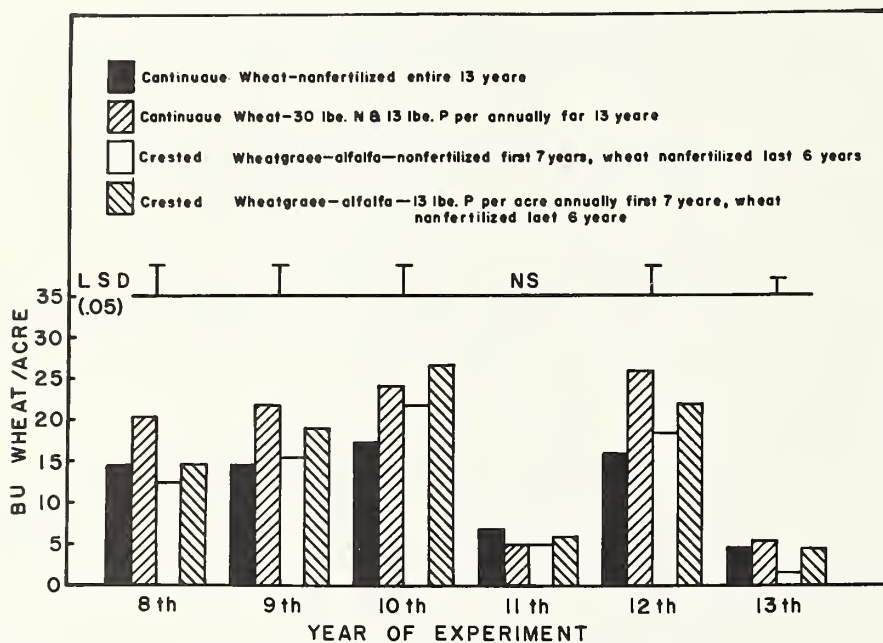


FIGURE 2.—Wheat yields after 7 years of different cropping and fertilizer treatments (harvested) in Experiment II of the Fine Sandy Loam Study.

Footnotes for table 8.

¹One-half of each plot did not receive fertilizer, except previously fertilized continuous wheat plots which continued to receive 30 lbs N and 13 lbs P per acre the last 6 years.

²One-half of each plot received 30 lbs of N per acre annually the last 6 years, except the previously fertil-

ized continuous wheat plots, which received 60 lbs N and 13 lbs P per acre.

³See footnote 3, table 7.

⁴See footnote 2, table 3.

⁵See footnote 3, table 3.

were higher than those from fertilized continuous wheat only in the 10th year.

Residual effect of crested wheatgrass and sweet clover on wheat yields was greater than that from crested wheatgrass and alfalfa in several instances and particularly in the 8th year (first year after sod). Results from four of the treatments in Experiment II are also shown in figure 2. Previous harvesting treatments in Experiment II influenced wheat yields which followed in all except low rainfall years (11th and 13th).

In the Silt Loam Study (table 8), cropping and fertilizer treatments the first 7 years influenced wheat yields significantly the last 6 years in all but the low rainfall years (11th and 13th). Continuous wheat which received N and P fertilizer throughout the entire 13 years produced highest yields in the 8th, 9th, and 12th years. Crested wheatgrass-alfalfa (0-13 treatment) produced highest wheat yield in the 10th year. Yields following crested wheatgrass-alfalfa were much lower than from other treatments in the 8th year and slightly lower in the 9th year because of less soil water following alfalfa. Results for four of the treatments are presented graphically in figure 3. The addition of 30 pounds of N to one-half of each plot the last 6 years significantly increased mean

wheat yields in 2 years, reduced yields in 2 years, and had no effect on yields in 2 years (table 8).

Percentage Nitrogen in Wheat Grain

The effect of previous cropping and fertilizer treatments on N concentration of wheat grain was significant in 3 of the last 6 years for harvested and nonharvested treatments in Experiment I of the Fine Sandy Loam Study (table 7). The effect in Experiment II was significant in 4 years for the harvested treatment and in all years for the nonharvested treatment. In the Silt Loam Study, the effect was significant in all cases except the fertilized treatment in the 11th (driest) year (table 8).

Greatest effect of previous treatments on N concentration of grain was observed in the 8th, 9th, and 10th years, particularly from plots that had been in nonfertilized crested wheatgrass-alfalfa. This treatment also had highest average N content of grain for the last 6 years. The effects of three treatments on the N concentration expressed as percentages of the nonfertilized continuous wheat treatment are shown in figure 4. Each year is calculated separately. Relative effect of the crested wheatgrass 60-0 treatment was greater than that of the continuous wheat 30-0 treatment in

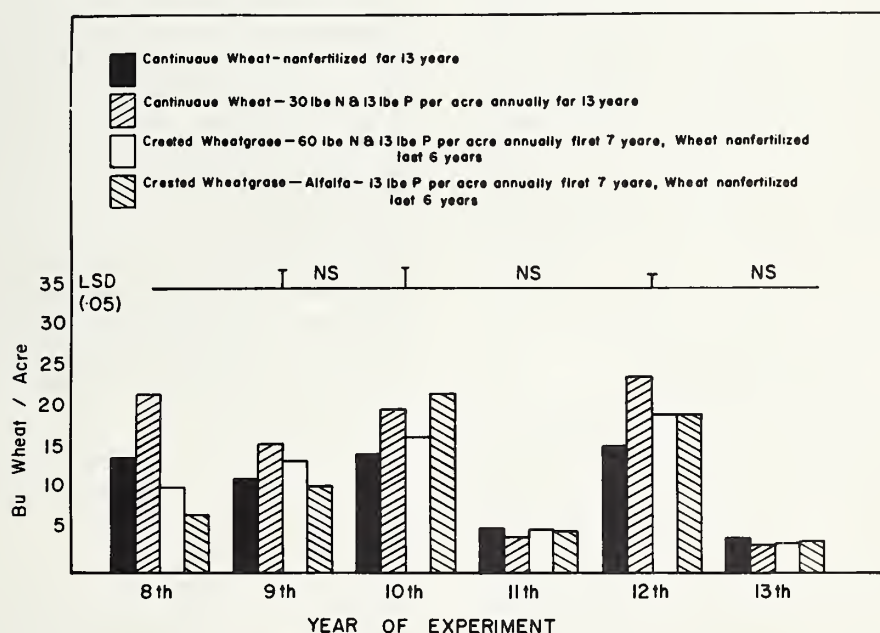


FIGURE 3.—Wheat yields after 7 years of different cropping and fertilizer treatments in the Silt Loam Study.

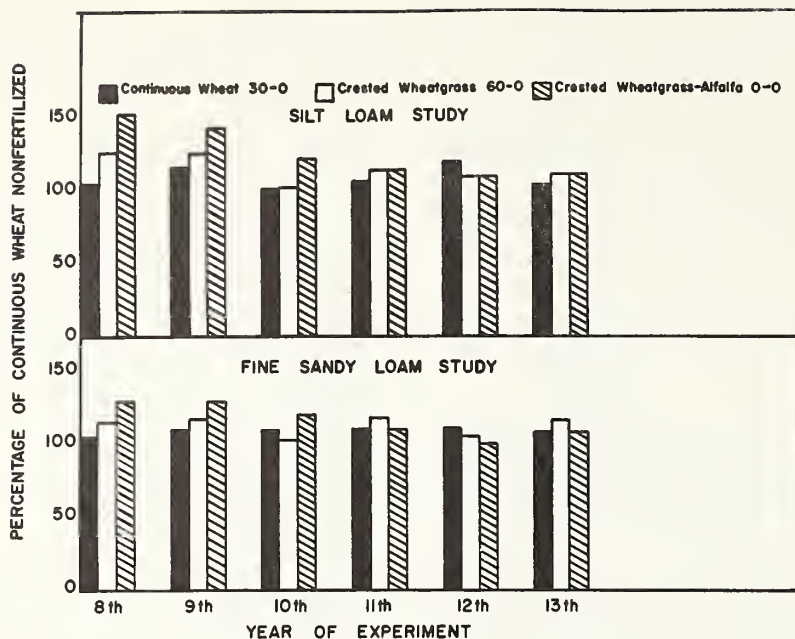


FIGURE 4.—Nitrogen content of wheat grain in last 6 years after 7 years of different cropping and fertilizer treatments expressed as a percentage of nonfertilized continuous wheat.

4 of the 6 years. Remember, the continuous wheat received 30 pounds of N per acre each year during the entire 13-year period in the Fine Sandy Loam Study, and during only the last 6 years in the Silt Loam Study.

Application of P tended to reduce N content of the grain (tables 7 and 8). Previous harvesting treatment in the Fine Sandy Loam Study (table 7) influenced N concentration of grain significantly in only 1 year in Experiment I and in 2 years in Experiment II. There was a significant difference between mean values for all years only in Experiment II. In the last 6 years the yearly addition of 30 pounds of N fertilizer in the Silt Loam Study increased N content of grain significantly in 5 of the 6 years (NF vs. F, table 8).

Percentage Phosphorus in Wheat Grain

Previous cropping and fertilizer treatments the first 7 years did not significantly influence P concentration of wheat grain in any of the last 6 years for the harvested treatment in Experiment I of the Fine Sandy Loam Study, but did significantly influence P concentration in 3 of the last 6 years for the nonharvested treatment (table 7). In Experiment II of the Fine Sandy Loam Study, the effect was signifi-

cant in 5 of the last 6 years for the harvested treatment and in 3 of the last 6 for the nonharvested treatment. Previous harvesting treatment influenced P concentration of wheat grain significantly in only the first of the last 6 years in each experiment of the Fine Sandy Loam Study.

In the Silt Loam Study (table 8), previous cropping and fertilizer significantly influenced P content of wheat grain in 5 of the last 6 years where no additional fertilizer was applied (NF treatment). Where 30 pounds of additional N was applied during this 6 years (F treatments), the effect of previous cropping and fertilizer was significant in 4 years. Mean P concentration of the grain was significantly reduced in 3 of the last 6 years by addition of 30 pounds of N during each of these last 6 years (table 8, NF vs. F treatments). The addition of N also significantly reduced mean P concentration of grain for all years.

In both studies, the application of N tended to reduce P content of grain compared to similar cropping treatments without N. This reduction was probably due partly to the dilution effect caused by increased growth and yield from N fertilizer. As would be expected, application of P usually, but not always, increased P content of grain.

Soil Water

At seeding

Plots that had been in either wheat or crested wheatgrass without fertilizer the first 7 years usually contained more soil water at wheat seeding time than other treatments during the last 6 years (tables 9 and 10). Plots that had been in a mixture of crested wheatgrass and alfalfa usually contained the least water.

Differences in soil water content caused by treatments the first 7 years were significant in only 1 of the last 6 years for either the harvested or nonharvested treatments in Experiment I of the Fine Sandy Loam Study (table 9). In Experiment II, differences were significant in 2 years for the harvested treatment and 3 years for the nonharvested treatment. Differences between means of harvested and nonharvested treatments were significant in only 1 year in Experiment I and in no years in Experiment II.

In the Silt Loam Study (table 10), effect of cropping and fertilizer treatment the first 7 years on soil water at seeding time was significant in 5 of the last 6 years where additional fertilizer was not applied during these last 6 years (NF treatment), and in 4 years where additional nitrogen was applied (F treatment). Differences between means of NF and F treatments were not significant in any years.

A comparison of soil water content by foot increments between nonfertilized continuous wheat and wheat following 7 years of crested wheatgrass-alfalfa (0-13 fertilizer treatment) is presented in figure 5. Soil water content at seeding in each foot increment below the first foot was lower every year following crested wheatgrass-alfalfa than under continuously cropped wheat. Little water apparently penetrated to the 3d foot for the crested wheatgrass-alfalfa treatment, whereas, water reached the 4th and possibly the 5th foot under nonfertilized continuous wheat by the 10th year. This may have increased the calculated N loss on nonfertilized continuous wheat. However, water moved below the 2-foot depth only in 2 of the last 6 years.

At harvest

Plots that had been in either wheat or crested wheatgrass without fertilizer the first 7 years usually contained more water at harvest, and

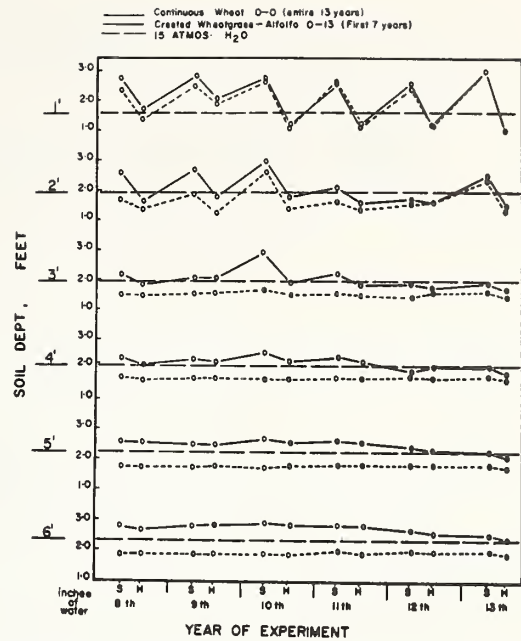


FIGURE 5.—Inches of water in each foot increment at seeding (S) and harvest (H) of wheat after 7 years of two cropping treatments in the Silt Loam Study.

plots which had been in crested wheatgrass-alfalfa usually contained the least water (tables 9 and 10).

In Experiment I in the Fine Sandy Loam Study, although there were differences in soil water caused by cropping and fertilizer treatments imposed during the first 7 years, differences were not significant in any year for harvested treatments and in only 2 years for the nonharvested treatment (table 9). In Experiment II previous cropping and fertilizer influenced water content at harvest significantly in 3 years for each of the harvested and nonharvested treatments. There was no significant difference between harvest treatments (H vs. NH).

In the Silt Loam Study (table 10), previous cropping or fertilizer influenced soil water content at harvest significantly in 5 years for both where fertilizer was not applied (NF treatment) and where fertilizer was applied (F treatment) during the last 6 years. Although differences between means of NF and F treatments were small (averaging 0.2 inch less for F treatments), they were significant in 4 years.

Soil water content at harvest in the Silt Loam Study is also presented in figure 5 by 1-foot increments to a depth of 6 feet for con-

TABLE 9.—Inches of water in the surface 6 feet of soil at wheat seeding and harvest last 6 years following 7 years of cropping and fertilizer treatments in the Fine Sandy Loam Study

Experiment	First 7 years cropping and fertilizer treatments	Year:	Soil water in surface 6 feet (inches)												Mean	
			8th		9th		10th		11th		12th		13th			
			H ¹	NH ²	H	NH	H	NH	H	NH	H	NH	H	NH	H	NH
SEEDING																
I	Wheat:															
	0-0 ³		16.4	12.5	15.2	13.0	15.4	12.6	14.6	12.3	13.0	10.3	15.2	13.6	15.0	12.4
	30-13		15.0	13.6	13.7	12.4	13.6	12.2	12.0	11.4	11.2	10.0	14.0	11.8	13.2	11.9
	Crested wheatgrass:															
	0-0		12.4	14.3	13.5	14.4	13.5	13.7	12.8	14.2	11.2	13.9	13.8	16.4	12.9	14.5
	30-0		10.1	9.8	10.1	10.2	12.0	10.3	9.0	9.3	10.1	9.5	11.2	10.9	10.4	10.0
	30-13		12.4	11.6	13.6	11.8	13.7	10.8	11.4	10.2	11.1	10.4	13.4	11.9	12.6	11.1
	60-0		9.8	9.4	10.4	10.8	11.2	10.5	11.0	8.7	10.9	9.4	11.8	10.8	10.8	9.9
	60-13		9.7	10.3	10.9	11.5	11.8	11.2	10.3	9.3	10.0	10.5	11.5	11.5	10.7	10.7
	Mean		12.3	11.6	12.5	12.0	13.0	11.6	11.6	10.8	11.1	10.6	13.0	12.4	12.2	11.5
LSD ⁴ (0.5) cropping and fertilizer treatments ...			4.2	NS ⁵	NS	NS	NS	NS	NS	3.2	NS	NS	NS	NS	NS	NS
Significance between harvest treatments			NS		NS		**5		NS		NS		NS		NS	
II	Wheat:															
	0-0		11.7	11.9	11.6	13.1	11.6	11.8	9.7	10.3	9.5	9.3	10.7	11.3	10.8	11.3
	30-0		11.9	10.6	11.5	10.8	10.5	10.4	9.2	7.2	7.9	6.9	10.2	7.1	10.2	8.8
	30-13		11.4	11.5	10.4	10.4	10.3	11.3	10.2	9.6	8.1	8.1	10.4	11.3	10.1	10.4
	Crested wheatgrass and alfalfa:															
	0-0		7.0	6.8	10.1	9.2	8.8	9.3	6.6	6.7	7.3	7.4	8.2	8.2	8.0	7.9
	0-13		7.0	6.7	9.4	8.6	8.9	8.6	6.9	7.1	7.0	6.6	10.0	8.1	8.2	7.6
	Crested wheatgrass and sweet clover:															
	0-0		8.6	10.9	11.4	10.8	10.3	11.0	9.5	9.9	7.4	8.3	8.7	10.3	9.3	10.2
	0-13		8.5	11.4	9.8	11.1	9.8	11.2	8.6	8.8	8.7	8.4	8.6	9.9	9.0	10.1
	Mean		9.4	10.0	10.6	10.6	10.0	10.5	8.7	8.5	8.0	7.9	9.5	9.5	9.4	9.5
LSD (.05) cropping and fertilizer treatments ...			1.4	2.6	NS	2.4	1.4	NS	NS	NS	NS	NS	NS	2.5	1.4	2.3
Significance between harvest treatments			NS		NS		NS		NS		NS		NS		NS	
HARVEST																
I	Wheat:															
	0-0		11.0	10.0	9.3	9.0	10.8	9.4	10.2	8.9	10.9	9.5	10.3	8.6	10.4	9.2
	30-13		10.3	8.8	9.2	8.5	8.7	7.2	8.9	8.2	10.3	7.9	8.3	7.8	9.3	8.1
	Crested wheatgrass:															
	0-0		11.2	12.0	9.3	10.4	9.0	9.9	9.2	11.5	9.4	12.4	8.9	10.1	9.5	11.0
	30-0		8.4	8.1	7.5	6.8	6.8	6.0	7.1	6.1	7.9	7.3	6.5	6.6	7.4	6.8
	30-13		10.2	10.5	9.3	8.3	8.7	7.1	8.7	7.3	9.6	9.0	8.6	7.4	9.2	8.3
	60-0		7.4	8.2	7.0	6.8	7.4	7.4	7.7	7.4	9.0	8.4	7.8	7.0	7.7	7.5
	60-13		8.4	7.9	6.7	7.2	7.4	7.9	8.2	7.9	8.9	8.4	7.5	7.5	7.8	7.8
	Mean		9.6	9.4	8.3	8.1	8.4	7.8	8.6	8.2	9.4	9.0	8.3	7.9	8.8	8.4
LSD (.05) cropping and fertilizer treatments ...			NS	2.6	NS	1.8	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Significance between harvest treatments			NS		NS		NS		NS		NS		NS		NS	
II	Wheat:															
	0-0		8.7	9.6	8.1	9.1	7.1	6.9	7.4	8.5	8.0	8.1	6.6	7.1	7.6	8.2
	30-0		8.3	7.3	7.8	7.9	6.0	5.9	6.8	5.2	6.4	5.0	6.1	4.7	6.9	6.0
	30-13		8.1	8.2	7.9	7.9	8.2	7.7	5.7	7.9	6.8	7.4	6.0	7.0	7.1	7.7

TABLE 9.—Inches of water in the surface 6 feet of soil at wheat seeding and harvest last 6 years following 7 years of cropping and fertilizer treatments in the Fine Sandy Loam Study—Continued

Experi- ment	First 7 years cropping and fertilizer treatments	Year:	Soil water in surface 6 feet (inches)													
			8th		9th		10th		11th		12th		13th		Mean	
			H	NH	H	NH	H	NH	H	NH	H	NH	H	NH	H	NH
HARVEST																
II	Wheat—Continued: Crested wheatgrass and alfalfa:															
	0-0	6.1	5.9	6.0	5.8	5.3	5.4	5.1	5.3	5.2	5.2	5.1	4.5	5.5	5.4	
	0-13	5.7	6.0	5.8	5.2	5.0	5.2	5.6	5.2	5.4	5.1	5.8	4.9	5.6	5.3	
	Crested wheatgrass and sweet clover:															
	0-0	7.2	9.2	7.6	8.0	7.2	7.9	7.4	7.7	6.8	7.4	6.5	6.1	7.1	7.7	
	0-13	7.1	8.1	7.1	7.4	8.2	6.4	6.9	7.4	6.6	7.1	6.0	6.3	7.0	7.1	
	Mean	7.3	7.8	7.2	7.3	6.7	6.5	6.4	6.7	6.5	6.5	6.0	5.8	6.7	6.8	
LSD (.05) cropping and fertilizer treatments ...		1.1	NS	NS	NS	2.1	NS	NS	2.4	1.5	2.2	NS	1.5	1.1	2.2	
Significance between harvest treatments		NS		NS		NS		NS		NS		NS		NS		

¹See footnote 1, table 7.

²See footnote 2, table 7.

³See footnote 3, table 7.

⁴See footnote 2, table 3.

⁵See footnote 3, table 3.

tinuous wheat nonfertilized and for plots which had been in crested wheatgrass-alfalfa during the first 7 years. Soil water content at harvest in the 2d through the 6th foot was lower, with one exception, in all years in those plots cropped to crested wheatgrass-alfalfa the first 7 years. During the first 4 of the last 6 years, nonfertilized continuous wheat was unable to dry the 2d foot of soil as much as did wheat following crested wheatgrass-alfalfa.

Growth of wheat following crested wheatgrass-alfalfa was more luxuriant than that

of nonfertilized continuous wheat possibly because of more available nitrogen. Root growth of wheat may also have been greater on plots which had been in crested wheatgrass-alfalfa the first 7 years, enabling these plants to extract more water than nonfertilized continuous wheat plants. Although water content in the 4th through 6th foot remained nearly constant throughout the last 6 years following crested wheatgrass-alfalfa, there was a decrease in water content at these depths with continuous wheat.

CONCLUSIONS

Results from these studies indicate that soil N can be maintained or increased about as well with N fertilized continuous wheat as with N fertilized crested wheatgrass or with a crested wheatgrass and alfalfa or sweet clover mixture. When crops were mowed and left on the soil surface instead of being harvested during the first 7 years, significant differences existed in soil N changes because of cropping and fertilizer treatments. Greatest gains in soil N occurred with the crested wheatgrass-alfalfa mixture, which also had the greatest organic mat on the surface.

Alfalfa apparently fixed over 800 pounds of N during the first 7 years, but over 700 pounds of N were removed in the crested wheatgrass and alfalfa forage, so little N accumulated in the soil under this treatment where the crop was harvested.

The effect of the various cropping and fertilizing treatments on soil organic C content was similar to that for N except gains in organic C were higher in some instances. Of particular interest was the tendency, under similar cropping treatments, for the organic C content to increase with increasing rates of applied N.

TABLE 10.—Inches of water in surface 6 feet of soil at wheat seeding and harvest in last 6 years following 7 years of cropping and fertilizer treatments in the Silt Loam Study

First 7 years cropping and fertilizer treatments	Soil water in surface 6 feet (inches)														
	Year:	8th		9th		10th		11th		12th		13th		Mean	
	NF ¹	F ²	NF	F	NF	F	NF	F	NF	F	NF	F	NF	F	
SEEDING															
Wheat:															
0-0 ³	15.5	15.3	15.4	14.6	17.0	16.6	14.9	14.0	13.4	13.5	14.4	13.8	15.1	14.6	
30-13	15.3	14.5	14.5	13.9	14.9	14.9	13.3	12.7	12.8	12.4	13.8	13.4	14.1	13.6	
Crested wheatgrass:															
30-0	12.2	12.6	12.6	12.9	13.4	14.2	12.5	12.4	12.6	12.3	13.6	13.8	12.8	13.0	
30-13	12.1	12.3	12.8	13.0	13.4	13.5	12.6	12.4	12.6	12.4	14.1	14.0	12.9	12.9	
60-0	12.5	12.3	12.4	12.6	14.0	13.6	12.1	12.5	13.2	12.3	13.8	13.2	13.0	12.8	
60-13	12.0	12.0	12.1	12.6	13.5	13.4	12.6	12.5	12.6	12.7	13.8	13.5	12.8	12.8	
Crested wheatgrass and alfalfa:															
0-0	11.2	11.2	11.7	11.8	12.6	13.3	12.8	13.1	11.8	11.6	13.4	12.6	12.2	12.3	
0-13	11.0	11.1	11.3	11.8	12.3	12.7	11.4	11.8	11.1	11.2	12.6	12.8	11.6	11.9	
Mean	12.7	12.7	12.8	12.9	13.9	14.0	12.8	12.7	12.5	12.3	13.7	13.4	13.1	13.0	
LSD ⁴ (.05) cropping and fertilizer treatments ...	1.4	1.3	0.8	0.7	1.2	1.1	1.6	NS ⁵	0.9	0.8	NS	NS	0.7	0.9	
Significance between last 6 years' fertilizer treatments	NS		NS		NS		NS		NS		NS		NS		
HARVEST															
Wheat:															
0-0	12.9	12.7	13.7	12.8	12.7	11.9	12.3	11.2	11.6	11.1	10.5	9.9	12.3	11.6	
30-13	12.2	12.0	12.3	11.9	11.4	11.1	11.4	11.2	11.2	10.5	10.2	10.0	11.4	11.1	
Crested wheatgrass:															
30-0	10.9	11.4	11.1	11.5	10.8	10.3	10.9	10.7	10.6	10.6	10.3	9.8	10.8	10.7	
30-13	10.4	11.4	11.0	11.3	10.4	10.4	11.0	10.7	11.0	11.1	10.2	10.2	10.7	10.8	
60-0	11.0	10.6	11.6	11.1	10.8	10.6	10.9	10.5	10.9	9.6	10.0	9.8	10.9	10.4	
60-13	10.8	11.4	11.3	11.0	10.7	10.3	10.5	10.4	10.4	10.5	10.2	9.9	10.6	10.6	
Crested wheatgrass and alfalfa:															
0-0	10.6	10.3	10.7	10.6	9.6	9.6	9.9	10.0	9.9	9.6	9.4	9.2	10.0	9.9	
0-13	9.6	10.1	10.2	10.4	9.4	9.5	9.5	9.6	9.9	9.5	9.2	9.2	9.6	9.7	
Mean	11.0	11.2	11.5	11.3	10.7	10.5	10.8	10.5	10.7	10.3	10.0	9.8	10.8	10.6	
LSD (.05) cropping and fertilizer treatments ...	0.8	1.4	0.5	0.8	0.9	0.9	0.6	0.6	NS	1.2	0.6	NS	0.6	0.8	
Significance between last 6 years' fertilizer treatments	NS		NS		**5		*5		**		*		*		

¹See footnote 1, table 8.

²See footnote 2, table 8.

³See footnote 3, table 7.

⁴See footnote 2, table 3.

⁵See footnote 3, table 3.

Residual effects of the various cropping and fertilizer treatments significantly affected annually cropped wheat yields in most cases during 4 of the last 6 years of uniform cropping. Yields were low in 2 of these years because of inadequate precipitation, which resulted in generally nonsignificant yield differences. Highest mean wheat yields during the last 6 years were obtained from plots which had been

annually cropped to wheat and which received N and P fertilizer throughout the entire 13 years of study. In only 1 of the last 6 years did highest wheat yield occur on plots previously in a mixture of crested wheatgrass and alfalfa. Plots which had been in sod crops during the first 7 years, particularly alfalfa, contained less stored subsoil water during the last 6 years.

From the standpoint of spring wheat produc-

tion on dryland in the Northern Great Plains, to annually crop wheat and fertilize would be better than to attempt to improve the soil with present grass or legume crops and fertilizers. Residual effects of sod crops upon subsequent wheat yields were generally minimal with a tendency to be detrimental rather than beneficial because of reduced water availability.

Mean wheat yields following cropping treatments in which the crops were harvested and removed for 7 years were usually slightly less than those for treatments in which the crops were mowed and left on the surface. Difference between mean yields because of previous harvesting treatment was significant in about half of the comparisons.

Where wheat followed 7 years of crested wheatgrass and alfalfa, N or protein content of the grain was generally higher, particularly during the first 3 years after plowing under the sod, than following other cropping and fertilizer treatments. This resulted in a higher mean N content of grain for the last 6 years for this treatment.

Nitrogen fertilizer tended to increase N content of grain but to reduce P content. Conversely, P fertilizer tended to increase P content of grain but to reduce N content. Apparently, the effect of fertilizer on N or P content of grain is dependent upon a yield response. If a yield response is obtained, then nutrient content may be reduced through a dilution effect.

ACKNOWLEDGMENT

The authors acknowledge the assistance of the following: R. W. Carpenter for helping initiate and conduct the experiments, G. O. Boatwright for assistance in data collection, R. F. Follett for assistance with statistical

analyses, D. L. Grunes for supervision of laboratory analyses, and E. P. Bickel and R. T. Vredenburg for laboratory analyses and technical support.

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